

SUSTAINABLE, AFFORDABLE HOUSING— MOVING TOWARDS ZERO ENERGY

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INTRODUCTION

In 2010, Rural Development, Inc. (RDI) completed construction of Wisdom Way Solar Village (WWSV), a community of 20 homes (ten duplexes) in Greenfield, MA. RDI was committed to very low energy use and sustainable building practices from the outset as they assembled a committed design and construction team. The team worked together closely to optimize site planning, home design and envelope systems, IEQ strategies, sustainable materials, and HVAC and solar systems.

Most of the homes were reserved for low- and moderate-income buyers, and most of the buyers were first-time homeowners. RDI coordinated outreach and training for buyers about the homes' design and advanced systems.

The homes' design, orientation, and excellent building envelope allowed for very simple HVAC systems—saving RDI \$4,000 or more per home when compared to their standard HVAC systems. All of these building systems—combined with active solar electric and thermal systems—resulted in average gas and electric bills of less than \$350 per year (14% of the regional average, EIA). The homes also achieved LEED for Homes certification at the Platinum level.

The author (an engineer with Steven Winter Associates, SWA) worked with RDI through the design and construction process and conducted evaluations of several building systems before and during occupancy.

KEYWORDS

affordable housing, LEED for Homes, building envelope, HVAC, solar water heating, solar electric, zero-net electric

PLANNING AND DESIGN

Project Team

When RDI—the builder and developer—first became aware of this available land, they saw real value in assembling a design team early on in the project. In addition to several people from RDI, the design team included architects, the civil engineer, the landscape architect, the mechanical engineer and energy consultant, RDI's lawyer, solar contractors, plumbers, the electrician, site and foundation contractors, a utility representative, the home energy rater, and other specialists as needed. Not every member of the team attended every meeting, but

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FIGURE 1. One of the WWSV duplexes.



having this group of committed professionals willing and able to address problems and meet as needed was critical to the project's success. The team continued working together to address concerns and resolve issues as the build-out of the project progressed.

In addition to the professional design team, RDI also organized periodic meetings with interested members of the community and potential homebuyers to evaluate their concerns and suggestions for the project.

During early meetings to discuss this potential new project, the team determined that the site could support 20–25 dwelling units and still leave substantial room for open space. Designers worked with the town of Greenfield to evaluate various development options. The final plans called for a condominium community consisting of twenty dwelling units in ten duplexes.

Site Planning

Careful site planning can be one of the most important—but too often oversimplified—elements in designing communities of high-performance homes. This infill site was a very level field with very few trees or other obstructions. Before these homes were built, the site had been used as overflow parking for the nearby county fairgrounds. The design team met very early in the process to consider:

- Creating a “neighborhood” rather than a typical suburban development
- Providing open space for recreation, gardening, etc.
- Incorporating utilities and roads efficiently
- Southern orientation for all homes to allow for passive and active solar
- Functional landscaping that would not cause detrimental shading
- Making the community accessible to people with disabilities

The design team explored various clustered-development options, but the site plan finally approved by town officials is shown in Figure 2. The ten duplexes (twenty units) were sited to ensure solar access for all homes. Open space was preserved in the northwest corner of the site,

and a narrow strip on the western edge of the block (which is shaded by tall trees to the west) was also left open. SWA worked with RDI and Joan Rockwell & Associates, the landscape architect, to specify maximum mature heights for plantings so solar access to homes would not be compromised now or in the future.

Home Plans

The community consists of twenty homes with gross floor areas of 1,140 ft² (2 bedrooms), 1,390 ft² (3 bedrooms), and 1,770 ft² (4 bedrooms). Most homes feature an open downstairs plan containing living, dining, and kitchen areas, as well as a powder room. Upper floors generally contain bedrooms and a full bath. In single-story homes, the living, dining, and kitchen areas are toward the south, while the bedrooms and bathroom are toward the north.

The homes' modest sizes are consistent with affordable housing in the area. The simple geometry—basically rectangular or square—both simplifies construction and minimizes the wall areas (in relation to floor area). Smaller envelope areas are obviously less expensive to construct and heat loss from a building is also directly proportional to envelope areas.

BUILDING SPECIFICATIONS

In addition to outlining specifications and construction details, this section of the report also describes decision-making processes, challenges that occurred during construction, and recommendations for improving on these construction techniques.

Basement

All homes have full, unconditioned basements. The first-floor joist bays were insulated with 11.5" of blown cellulose for approximately R-39 ft²hr°F/Btu (see Figure 3).

Whenever possible, the author recommends insulating foundation walls rather than the floors above basements. Insulating basement walls can result in warmer, dryer, and more usable basement spaces. RDI determined that insulating the floors was much less costly and more practical for this project.

FIGURE 2. Site and landscape plan from Joan S. Rockwell & Associates. North is directly toward the top of the page.



FIGURE 3. Ceiling of a basement insulated with blown cellulose.



Above-Grade Walls

One of the key features in these homes are the double walls. Each exterior wall began with a load-bearing, 2x4 framed wall (framing at 16" on center). Carpenters then enclosed the entire envelope (wall sheathing, roofing, windows, doors, etc.). Once a home was enclosed, carpenters began interior framing and constructed an additional 2x4 wall five inches inside of the existing, exterior wall. Fiber-reinforced polyethylene or insulation netting was stapled to the inner studs, and the entire 12" wall cavity was filled with dry-blown cellulose insulation at densities of 3.4–4 lbm/ft³. The overall R-value of the wall assemblies is approximately 40 ft²ft²°F/Btu.

Double-wall construction seemed to work very well for RDI for three key reasons:

- The homes are designed with double-wall construction in mind. The perimeters of the homes are basically rectangular with very few interruptions (each home has one box bay). Employing the double-wall technique on more complicated plans with more dormers, gables, angles, and bays, etc., would be more time- and material-intensive.
- RDI had a core group of carpenters (RDI employees) that built the homes. RDI did not have to rely on (or train) outside framing contractors for this specialized job.
- Unlike foam or fiberglass, cellulose is a recycled material and has less environmental impact (and provides LEED credits).

FIGURE 4. Typical wall section from Austin Design, Inc. Insulation netting was used instead of rigid insulation between floor joists.

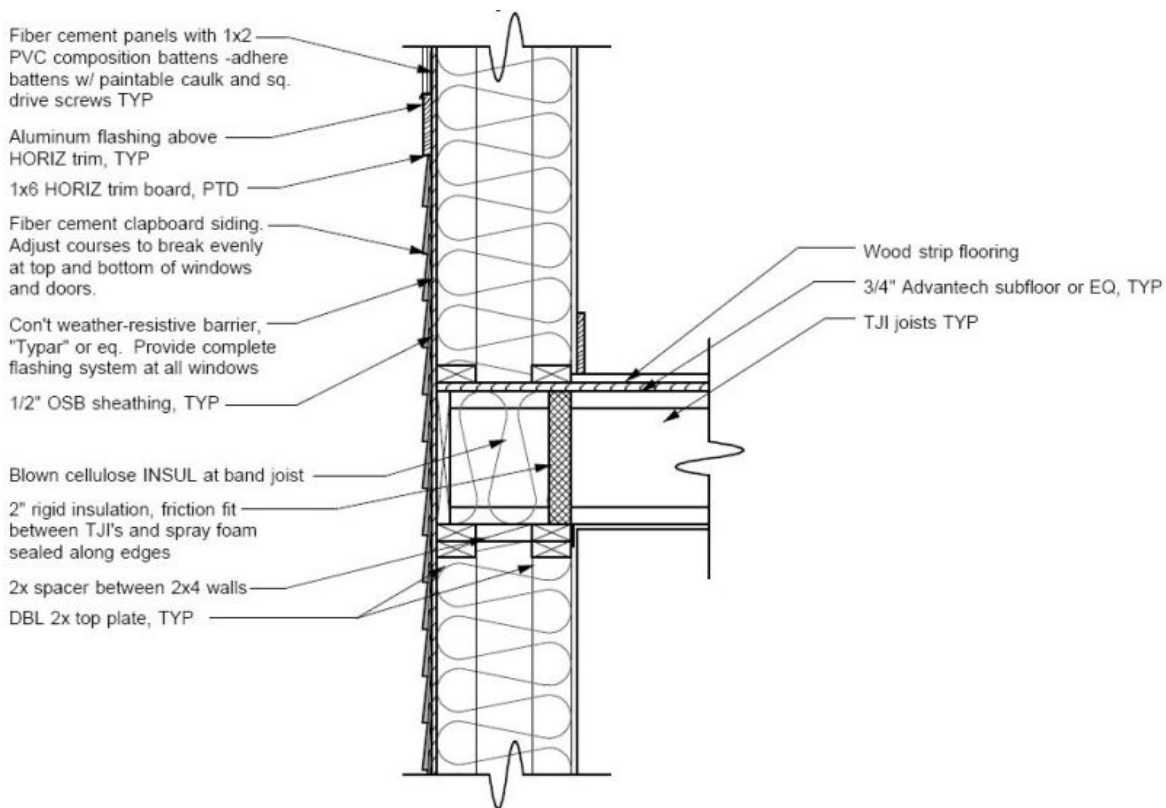


FIGURE 5. Double walls before and after cellulose insulation.



These factors kept the added costs for double walls lower. The author surveyed RDI's carpenters and insulators to assess the added time and material needed for these double-wall systems. Incremental cost for these walls—when compared to RDI's standard 2×6 construction—was approximately \$4,000 per home.

Attic

Construction of the vented attics was fairly typical. Roofs were constructed with manufactured, raised-heel trusses, and the attics incorporate full soffit and ridge vents and full-width insulation baffles at every truss bay. Homes were insulated with 14" of loose-blown cellulose for an R-value of approximately 50 ft²hr°F/Btu. Incremental cost for this insulation (over the typical R-38) was approximately \$300 per home.

Windows

RDI had typically obtained low-e, vinyl-framed windows from Paradigm Windows, a manufacturer based in Portland, ME. Paradigm makes double-pane, low-e windows with foam-filled frames that achieve U-values of 0.26 Btu/ft²hr°F and solar heat gain coefficients (SHGCs) of 0.28.

For the Wisdom Way development in Greenfield, RDI chose Paradigm's triple-pane window product with U-values of 0.18 Btu/ft²hr°F and SHGC of 0.23. While these provide excellent thermal performance, the visible transmittance (VT) of the windows was rather low (0.37) and the low solar heat gain would not allow tremendous passive solar gains during the winter.

RDI and SWA contacted many other window manufacturers searching for an affordable window with more desirable thermal properties, but they eventually came back to Paradigm. Paradigm offered to provide double-pane windows with the low-e coating on surface 3 (basically the reverse of their standard low-e product). This configuration raised the solar heat gain coefficient to 0.37. These higher-gain windows were used on the southern facades of the homes. Cost of the triple-pane windows was approximately \$35/ft², 55% more than

the \$23/ft² for double-pane windows. This increased the window cost for a three-bedroom WWSV home by \$1,436.

While the improved thermal properties of the windows result in rather modest savings on their own (approximately 18 therms of natural gas per year), the triple-pane windows can do a lot to improve occupant comfort on cold days. Designers were reluctant to use the simple HVAC systems (described below) without excellent window performance.

Air Sealing

Since RDI began building ENERGY STAR homes, they have paid more and more attention to creating air-tight envelopes. Sealing joints in sheathing, around windows and doors, all penetrations in plates and walls, etc., is standard practice. Blower door testing on the WWSV homes showed leakage in the range of 200–350 CFM when homes were depressurized to 50 Pa (approximately 1.5 ACH₅₀).

Heating Systems

Because of the superb envelope, the design heat loads of these units are very small: 9,000–13,500 Btu/hr. With the very small loads, RDI chose very small, simple heating systems: a sealed-combustion, natural gas-fired room heater located in the central area on the first floor of every unit (Monitor Products model GF-1800). In previous projects, RDI's standard heating system had been an ENERGY STAR boiler (either gas or oil) fueling hydronic baseboard convectors. The unit heater system results in savings of at least \$4,000 and helps offset the significantly higher envelope costs.

SWA discussed comfort in the homes at length with RDI. To alleviate concerns about temperature differentials—and to improve ventilation performance—SWA worked with RDI to design a very simple air-distribution system. To assure comfort in bathrooms, each full bathroom upstairs contains a small, 500-Watt electric resistance heater. The electric heaters are wired to a crank timer so they cannot be left ON for long periods of time.

In conjunction with researchers from the National Renewable Energy Laboratory (NREL), SWA performed short-term thermal comfort testing of one of the first completed

FIGURE 6. With the excellent envelope, this gas heater can provide space heating to the entire home.



Wisdom Way homes in February 2009. As expected, testing showed that unoccupied, upstairs bedrooms with doors closed were substantially cooler than the downstairs living room. However, when doors were opened or when a small load was introduced (using a 60-watt lamp), bedroom temperatures were much closer to downstairs temperatures.

SWA followed this short-term testing with longer-term tests of four occupied homes during the winter of 2009–2010. This monitoring found that upstairs bedrooms were usually slightly cooler than downstairs spaces (where the heater was located). None of the occupants, however, had major complaints about comfort. Some occupants surveyed were quite pleased, saying that comfort in the home exceeded expectations.

Much more information about these heating systems, test results, occupant interviews, and other implications of these systems can be found in the report, “Point-Source Heating Systems in Cold-Climate Homes: Wisdom Way Solar Village” (CARB 2010).

Ventilation Systems

The WWSV dwellings use an exhaust-only ventilation strategy. In the primary bathroom of each home, a very efficient exhaust fan (Panasonic model no. FV-08VKSL1) was installed and programmed to run continuously to meet the whole-building ventilation requirements of ASHRAE Standard 62.2-2007 (30–60 CFM, depending on the home size). The fan is also equipped to boost to high speed (80 CFM) for an adjustable amount of time when the bathroom is in use.

Exhaust-only ventilation is a common, affordable ventilation system for small homes in northern climates where air conditioning and duct systems are not always installed. For RDI—a developer of affordable housing for many first-time homeowners—an additional appeal of exhaust-only systems is the very low maintenance required. From an energy standpoint, new exhaust fans with BPM motors typically use 5–11 Watts. With such low power consumption, the overall energy and operating costs of these exhaust-only systems are less than those of some heat- or energy-recovery ventilation systems.

In homes at Wisdom Way Solar Village, RDI incorporated a simple air-distribution system to minimize discrepancies in air changes. As an added benefit, the system also helps to equalize air temperatures between spaces in the home. Each home contains an additional exhaust fan that “exhausts” air from the ceiling of the first floor and distributes a small amount of air (20–25 CFM) to each bedroom. Tests showed that this simple system did indeed help equalize temperatures and outdoor air distribution.

Lights and Appliances

RDI participated in an ENERGY STAR program sponsored by the local utility (Western Massachusetts Electric Company, WMECO). As part of this program, RDI received screw-in compact fluorescent lamps in all fixtures throughout the homes. All appliances provided by RDI (refrigerators and dishwashers) were also ENERGY STAR rated.

Water Heating

Most of the energy needs for domestic water heating in the homes are provided by solar thermal systems. Flat-plate solar collectors are mounted on the southern roof of each home, and a propylene glycol antifreeze solution circulates between the collectors and a heat exchanger located in a 110-gallon storage tank in the basement. Auxiliary water heating in each home is provided by a sealed-combustion, natural gas-fired, tankless water heater installed in the

FIGURE 7. Simple schematic of solar water heating system.

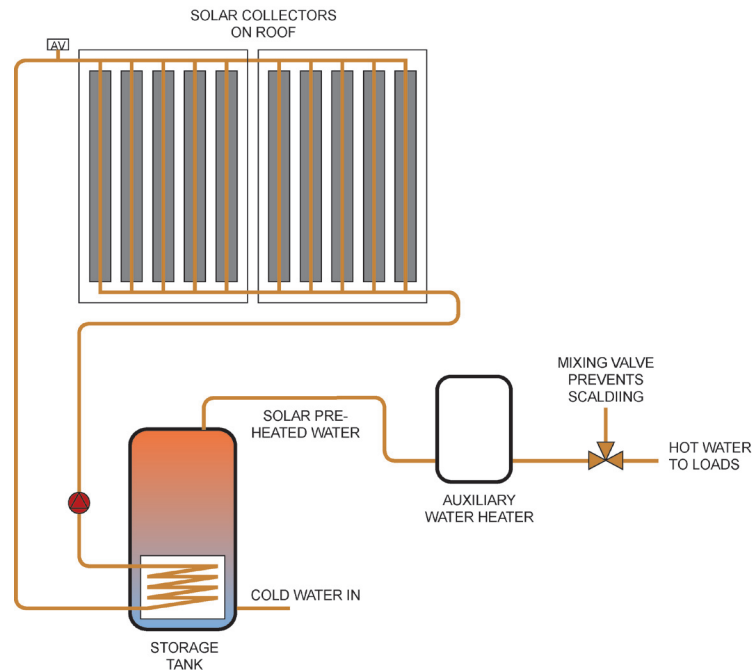
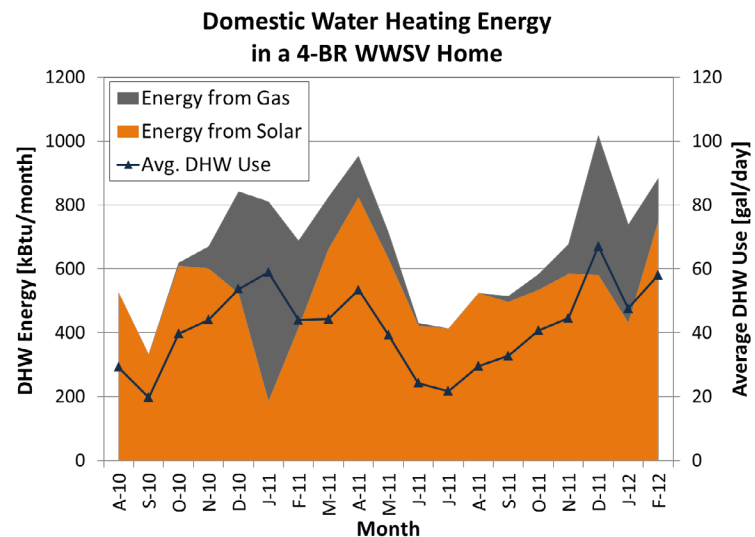


FIGURE 8. Performance of the solar water heating system at one WWSV home.



basement near the solar tank. Three- and four-bedroom homes have three, 29-ft² solar thermal collectors (Stiebel-Eltron Sol25); two-bedroom units have two collectors.

SWA has monitored solar thermal performance at one home in detail (see Figure 8). During the first 12 months monitored, the solar system in this home provided 79% of water heating energy; average hot water consumption was 39 gallons/day.

Solar Electric Systems

Each home has a solar electric system installed on the roof. Two-bedroom homes have 2.84-kW_{STC} PV systems; three- and four-bedroom homes have 3.42-kW_{STC} systems. All systems are installed flush on the roof (10/12 pitch, 40° tilt) and facing within 10° of true south. Each home has one inverter that is located in the basement.



FIGURE 9. Solar collectors installed on one home during construction. Solar electric modules (PV) are on the left; solar thermal collectors are in the background to the right.

UTILITY BILLS

Electricity

All buyers of the WWSV homes agreed to allow RDI to access their utility bill information. RDI was able to access electricity consumption data from 11 homes that have been occupied for at least one year. For the latest 12-month period analyzed, nine homes generated more energy than they consumed. Six homes generated enough excess electricity to offset all utility fees; these homes have net credits from the electric utility. Figure 10 shows average net electric consumption for the homes. As always, consumption patterns vary tremendously with occupants and habits. Some homes are consistently net generators; some consistently consume more than they generate.

Natural Gas Bills

The author obtained a full 12 months of gas data for nine occupied homes. The average annual gas consumption for these homes was 203 therms, for average annual gas costs of \$377, including all utility fees (which averaged approximately \$120 per year). Total annual gas costs ranged from \$183 to \$485.

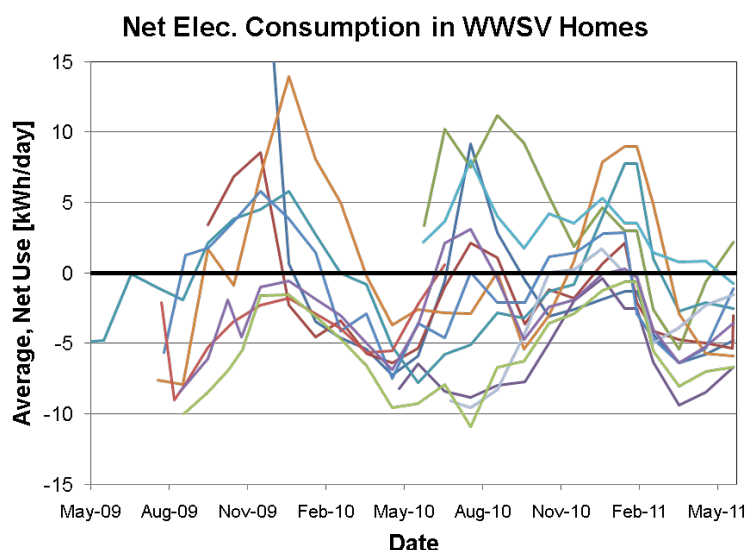
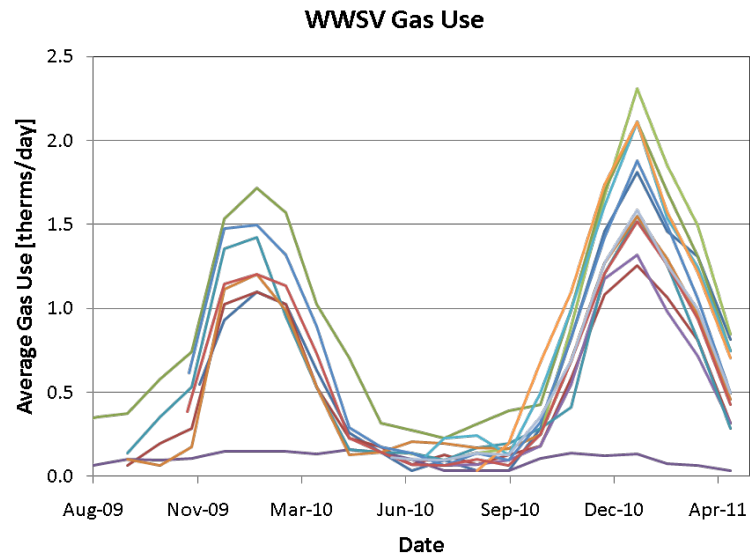


FIGURE 10. Average net electricity consumption in WWSV homes from monthly utility bills. Negative values indicate net generation.

FIGURE 11. Natural gas use in occupied WWSV homes.



Total Energy Costs

Between the two data sets, there are eight occupied homes for which complete energy bill data is available for an entire 12 months. Among these homes, the annual energy costs—including all utility fees—ranged from \$171 to \$458. The average cost for energy was \$337, or \$28 per month.

ENERGY IMPROVEMENT COSTS

The author worked with RDI, their contractors, and their suppliers to determine incremental costs of the advanced energy features as accurately as possible. An overview of these costs is shown in Table 1. Some rough estimates are unavoidable, especially with respect to time needed to install or implement these strategies (e.g., the double wall). These costs are specific to energy systems only. For example, RDI spent substantial resources making the homes more accessible and using sustainable materials; these costs are not reflected below.

As Table 1 shows, RDI received substantial subsidies for the energy improvements that went into the home. It's also worth considering the relative incremental costs of the envelope improvements (\$6,052), mechanical systems (savings of \$3,850), and solar systems (\$34,577).

DISCUSSION & CONCLUSIONS

RDI has been very pleased with the utility bills from the Wisdom Way Solar Village homes. The commitment and attention to detail on the part of RDI, the design team, and contractors was impressive, and it is gratifying to see average energy costs of \$337 per year. Below are discussions of several systems or issues that were very successful, challenging, or merit more investigation.

Double Wall System

RDI found that the double wall system worked quite well for them. While the system is quite labor-intensive, it was a buildable, cost-effective way to dramatically improve the homes' envelopes. One of the reasons a double-wall system worked especially well in these homes is that

TABLE 1. Approximate incremental costs for energy improvements to a 3-bedroom WWSV home. Incremental costs are compared to RDI's standard construction practices.

WWSV System	Standard Practice	Incremental Costs	
		Without subsidies	With Subsidies
Double-wall construction	2x6 walls, dense cellulose	\$3,776	\$3,776
R-50 attic insulation	R-40 attic insulation	\$300	\$300
R-40 floor insulation	R-30 batts	\$540	\$540
Triple-pane windows	Double-pane, low-e	\$1,436	\$1,436
Unit Heater	Boiler, hydronic baseboard	(\$4,000)	(\$4,000)
Tankless water heater	Indirect water heater	\$0	\$0
Exhaust only ventilation with mixing fan	Exhaust-only ventilation	\$600	\$450
100% CFL	100% CFL	\$0	\$0
ENERGY STAR Appliances	ENERGY STAR Appliances	\$190	\$190
Solar water heating system	NA	\$9,750	\$0
3.4-kW Photovoltaic system	NA	\$24,827	\$4,574
Total:		\$37,419	\$7,266

the homes were designed with double-walls in mind. The footprint of all homes is essentially rectangular—with a single box bay in each floor plan. There are no dormers, kneewalls, or variations in wall height on the same floor. During the design phase, the architects were very conscious of simplifying framing.

RDI found that good planning for wall penetrations—especially for appliance venting—is quite important. There were several meetings during construction when solutions for venting needed to be determined on-site. Planning for venting is always important, but with double walls, mistakes that require moving such penetrations are much more involved. Venting issues were further complicated by accessibility goals of the homes, discussed below.

Siding

As described above, the architects made great efforts to create simple floor plans to limit the framing time and cost associated with the double-wall system. This resulted in homes that were basically boxes. To make the homes more aesthetically appealing, the architects used several different siding styles and colors. Most agree that these aesthetics work very well, but the details involved in integrating fiber-cement clapboard, shingle, and panel proved to be more challenging, time-consuming, and expensive than planned. The actual increased siding costs were not available to the author, but these could be considered indirect costs related to the double-wall system.

Room Heaters

RDI was able to save several thousand dollars in each home by installing a single room heater. This is a non-conventional strategy, but SWA performed both short and long-term testing to evaluate the effectiveness of the heating system. Based on the monitoring results—and

FIGURE 12. Several WWSV homes.



interviews with occupants—the systems appear to provide adequate comfort with very low gas costs. SWA has reported on these results in much more detail in the report, “Point-Source Heating Systems in Cold-Climate Homes: Wisdom Way Solar Village” (CARB 2010).

Cost Effectiveness

As Table 1 shows, total incremental costs for energy improvements in a three-bedroom WWSV home—above RDI’s standard specifications—were \$37,419. After considerable subsidies, RDI’s increased costs were \$7,266. Modeled cost savings were \$2,335 per year per home.

Evaluation of cost-effectiveness is somewhat difficult, as sale prices of these affordable homes were largely proscribed by state and federal programs. If, however, the builder passed on these energy system costs to homebuyers—including a 10% margin—even without any subsidies the investments in efficiency and renewable energy provide a 6–7% rate of return when considering a 30-year mortgage. When subsidies are considered, the energy system investments provide a return of over 30%.

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